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PERFORMANCE PARAMETER WITH COATING AND SURFACE TEXTURING ON PISTON RING : AN OVERVIEW

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ABSTRACT

Reducing the energy consumption and exhaust emission, and improving the combustion efficiency of internal combustion engine are important for solving the problems of climate change and environmental pollution. The piston ring-liner system is one of the most serious friction pairs in internal combustion engine, accounting for 26% of the total friction loss.

This review paper explores various experimental techniques, coating materials, and texturing methods applied to piston rings. The aim is to enhance the performance, wear resistance, friction reduction, and overall durability of piston rings used in internal combustion engines.

The study highlights different coating technologies such as thermal spraying, DLC (Diamond-like Carbon), and ceramic coatings. Additionally, it discusses various surface texturing techniques, including laser texturing and micro-machining, for optimizing the tribological performance of piston rings.

KEYWORDS: Piston Ring, Coating, Surface Texturing, Efficiency, Friction

INTRODUCTION

One of the primary sources of power for mechanical equipment in the modern world is the internal combustion engine, which promotes the development of the aircraft, automotive, ship, and other industries. Additionally, it will continue to have a significant role in the power sector for a very long time, primarily in the fields of military vehicles, warships, and engineering machinery. However, with the aggravation of environmental pollution, greenhouse effect and oil depletion, how to reduce the energy consumption and emission becomes a challenging problem for the development of internal combustion engine.1 Solving this challenging problem needs measures from two aspects.

On one hand, the thermal efficiencies of internal combustion engine, that is the ratio of working output to fuel input can be improved through advanced technologies such as the progressive combustion technology, high pressurization and strengthening technology, waste heat recovery technology, intelligent variable technology, and low friction technology. In this measure, it is still necessary to continuously improve the thermal efficiency.

For a typical fired engine, mechanical friction is shown to take up roughly 4%–15% of the total fuel energy. The sources of friction loss are mainly concentrated on three components: the piston-ring-liner system, the crankshaft and bearing system, and the valve train system, as shown in Figure1.

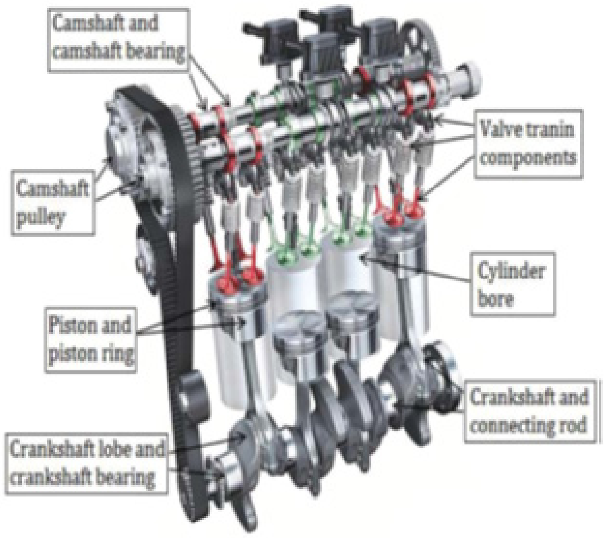

Figure 1: Typical components affecting the friction loss ofinternal combustion engine.[10]

The friction losses induced by them account for 50%–68%, 25%–35%, and 10%–20% of the total friction loss, respectively, among which friction loss of the piston ring reaches up to about 26%, as demonstrated in Figure 2.

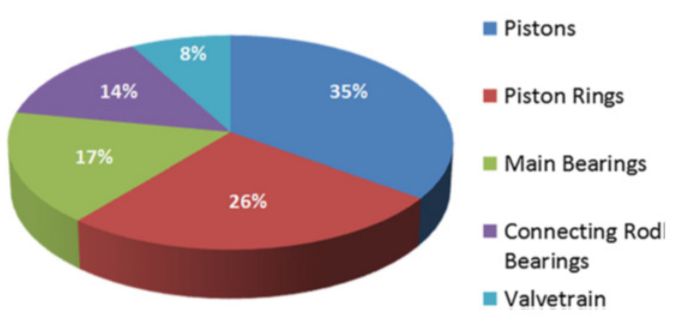

Figure 2: Distribution of friction losses in an automotiveengine. [11]

The internal combustion engine typically has three piston rings. The combustion chamber is sealed by the first gas ring. The compression ring is the second. The third component is the oil scraper ring, which is utilized to remove extra oil that has accumulated on the cylinder liner's inner circular surface.

These rings have two dominant characteristics. On one hand, the piston rings play important roles in modulating the oil film thickness, sealing the combustion gas in the chamber, controlling the position and guiding the movement of piston, conducting the heat of piston, and so on. However, large power losses can be produced during the operation of these piston rings, as shown in Figure 3,and therefore affect the thermal efficiency of the whole engine.

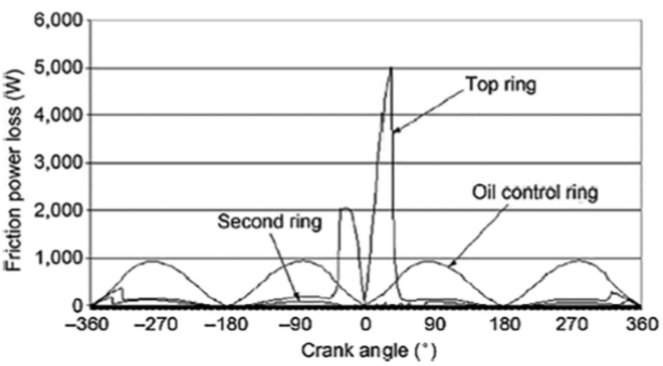

Figure 3: Friction power loss contributions in the piston ring pack for an 18 L natural gas engine at full load.[12]

In order to guarantee the durability and reliability of piston rings, their material should have good sealing property, high temperature resistance, corrosion resistance, wear resistance and low friction coefficient. According to these requirements, various materials of cast iron and alloy steel are applied in the production of piston rings. However, no matter using the cast iron or the alloy steel, single material is difficult to satisfy all the requirements of various characteristics of piston rings. To solve this problem, the surface coating technology, which makes it possible to design materials with special properties at the most desirable locations, is widely used in improving the surface property of piston rings. The positive aspect of depositing a coating on the piston ring is that it reduces the friction coefficient and wear rate, and improves the service life of the piston ring. Thus, the fuel consumption of the internal combustion engine is reduced and the service cycle of the internal combustion engine is extended. The negative aspect of depositing a coating on a piston ring is that the coating preparation process has been increased and the cost of using a single piston ring has increased.

In the modern automotive industry, fuel consumption combined with friction is a particularly important factor because of anticipated legal requirements on emissions. It is crucial to optimize the piston/cylinder system because it accounts for about 30% of the total friction

losses in internal combustion engines. Of these, 70–80% are attributable to the piston rings. In the past, the automotive industries deemed new materials, coatings, and high-tech procedures to be excessively costly. The two most important factors in lowering piston/cylinder friction are proper lubrication and surface roughness. Particularly in the last few years, laser surface texturing (LST) and preferred surface textures have emerged as exciting new technologies for reducing friction in mechanical components.

There are numerous benefits to laser surface texturing that could result in significant energy savings and improved mechanical system efficiency. The most evident benefit is the decrease in friction. In order to minimize friction power, which causes power loss, new technologies are needed. Numerous factors, such as load capacity, microspore geometry, speed, and materials used, affect the precise reduction of friction.

Compression ring coating and texturing are techniques used to reduce friction and improve the performance of internal combustion engines. Here's a brief overview:

Coating:
A thin layer of material applied to compression ring surface to reduce friction and wear

Common coatings include:
- Molybdenum-based coatings (e.g., molybdenum disulfide, MoS2)
- Ceramic-based coatings (e.g., silicon carbide, SiC)
- Diamond-like carbon (DLC) coatings

These coatings can reduce friction by up to 50% compared to uncoated rings

Texturing:
- The surface of the compression ring is modified to create a specific pattern or texture.
- Reduce friction by creating a hydrodynamic lubrication effect
- Improve oil retention and distribution
- Enhance ring durability
- Common texturing techniques include:
- Laser surface texturing
- Chemical etching
- Mechanical honing

By combining coating and texturing techniques, engineers can achieve even greater reductions in friction, leading to:
- Improved fuel efficiency
- Increased engine power and performance
- Reduced emissionsExtended engine lifespan

These technologies are widely used in the automotive industry and are particularly important for high-performance engines, where friction reduction can have a significant impact on overall efficiency and performance.

Advantages of LST
- Reducing metal-to-metal contact
- Facilitating speed/performance increase
- Up to 75% reduction in friction
- Enhancing component life and reliability
- Lengthening life in lubricant starvation situations
- Improving seizure resistance by two times
- Reducing power consumption
- Allowing extended service periods or downsizing
- Lower maintenance costs
- Assists in preventing catastrophic failures
- Reduces heat generation by thirty percent This could pay for itself in a matter of weeks.

Applications of LST
Current applications:
Since LST is still a relatively new field, its main application is in small-scale research. There are currently a few industrial applications for LST, including the proposed application in a car engine production line and in magnetic drives. The supplied parts and seals will also be textured by a number of specialized businesses. Many investigations are currently being conducted on a variety of applications for commercial use, such as:.
- Gas seals in turbines;
- Mechanical seals;
- Dual cone seals;
- Roller bearing thrust ribs
- Thrust Bearings;
- Thrust collars/washers;
- Water pump seals;
- Plain and hydrodynamic bearings;
- Surfaces lubricated by water or nonflammable solutions;
- High-temperature surfaces lubricated by ATF or other low viscosity lubricants;
- Reduces fretting corrosion;
- Magnetic drives;
- MEMS devices;
- Engines;

Metal forming as a conduit for a secondary hydrodynamic lubrication mechanism known as micro-pool or micro-plastic hydrodynamic lubrication. To enhance Osseo integration, LST-surfaced dental implants and bone are used.

Titanium Nitride (TiN) coating in IC engines offers several benefits:
1. **Reduced friction:** TiN coating has a low friction coefficient, which decreases friction between moving parts, resulting in improved engine efficiency and reduced wear.
2. **Improved durability:** TiN coating provides excellent wear resistance, extending the lifespan of engine components.
3. **Enhanced corrosion resistance:** TiN coating protects against corrosion, reducing damage from fuel and oil degradation products.
4. **Increased heat resistance:** TiN coating has high thermal stability, maintaining its properties even at high engine temperatures.
5. **Improved fuel efficiency:** Reduced friction and wear lead to improved fuel efficiency and reduced emissions.
6. **Reduced emissions:** TiN coating can help reduce emissions by minimizing oil consumption and reducing particulate matter.
7. **Improved engine performance:** TiN coating can lead to increased power output, torque, and engine responsiveness.
8. **Reduced maintenance:** TiN coating can reduce maintenance needs by minimizing wear and corrosion.

Common applications of TiN coating in IC engines include:
1. **Piston rings:** Reduced friction and wear on piston rings.
2. **Cylinder liners:** Improved durability and reduced wear on cylinder liners.
3. **Valve train components:** Reduced friction and wear on valve train components.
4. **Camshafts:** Improved durability and reduced wear on camshafts.
5. **Crankshafts:** Reduced friction and wear on crankshafts.

Overall, TiN coating can significantly enhance the performance, efficiency, and lifespan of IC engines.

LITERATURE REVIEW
1. Rita Ferreira et al The radial surface coating of compression piston rings enhances wear resistance in internal combustion engines. However, high friction at top dead center hampers performance. This study tested various dimple textures on piston rings, finding that a texture with a 0.25 aspect ratio and 15% area density delivered the lowest friction and best wear resistance.

2. Atulkumar S. Patil et al This study explores how various fiber laser parameters—power, frequency, speed, and number of loops—affect the texture dimensions (diameter, depth, and surface roughness) of circular textures fabricated on cast iron piston ring segments. The research aimed to achieve target values of 100 µm diameter, 20 µm depth, and 3 µm surface roughness with specific tolerances. Using a Marko Laser system and a confocal microscope for surface profiling, the study provides valuable insights into optimizing laser texturing processes for automotive components. Initially, increasing laser power reduced texture diameter but increased depth and surface roughness. Beyond a certain threshold, both diameter and depth increased, indicating enhanced ablation rates. Higher frequencies led to increased texture depth and surface roughness, with minimal effect on diameter. Increasing speed decreased texture dimensions, suggesting

insufficient material removal at higher speeds.Increasing loops caused fluctuations in depth and roughness, with minimal impact on diameter.

3. Yali Zhang et al The piston ring-cylinder liner pair is a key tribological system in internal combustion engines, contributing significantly to friction losses and overall efficiency loss. Enhancing its design can greatly reduce these losses and yield substantial economic benefits. This paper explores surface texturing as a promising method to improve the tribological performance of these sliding surfaces. This paper presents an experimental study using a pin-on-disk tribometer to evaluate how surface texturing affects friction reduction in piston rings under varying loads and sliding speeds. Rectangular and circular textures with different depths and area densities were created using a femtosecond laser, and results were compared against untextured rings. The results show that surface texturing significantly improved the friction performance of piston rings and shortened the running-in stage. Rectangular textures outperformed circular ones in reducing friction, with an optimal texture density identified for rectangular patterns. Additionally, the average friction coefficient reduction decreased with higher loads and increased with higher sliding velocities.

4. RYK, G. et al This experimental study investigates the effect of partial laser surface texturing (LST) on friction reduction in piston rings. Unlike full LST, which textures the entire ring width, partial LST textures only a portion with high dimple density, creating a collective hydrodynamic effect. Results using flat, parallel specimens confirm theoretical models and demonstrate that partial LST can outperform full LST. However, applying LST to actual production piston rings with crowned profiles requires further research due to its complexity.

5. Mahesh Dhonde et al.Titanium nitride (TiN), a prominent transition metal nitride (TMN), has garnered significant attention due to its exceptional characteristics and versatile applications in modern technologies. This comprehensive review highlights TiN's unique properties, positioning it as a promising alternative to traditional plasmonic metals due to its ability to overcome cost limitations and maintain plasmonic behaviour at lower temperatures. The paper presents recent research on TiN, encompassing various synthesis techniques, structural considerations, and its diverse range of applications. By focusing on the synthesis aspect, the review delves into the different methods employed to produce TiN, showcasing the breadth of available strategies. Additionally, the article sheds light on emerging applications where TiN demonstrates its prowess, such as solar energy acquisition, energy storage, photocatalysis, electrochemical sensing, biomedical implants, and protective coatings. Acknowledging the challenges and limitations of TiN, the review addresses potential areas for improvement and research directions. By offering a comprehensive analysis of TiN's capabilities, this review serves as an invaluable resource for researchers and scientists in the dynamic field of materials science and engineering. The synthesis strategies and extensive technological applications discussed here will undoubtedly inspire further exploration and innovation in using TiN for advancing cutting-edge technologies.

6. Lei Zhang et al.Little work has been reported directly compared to the tribological behavior of plasma nitrided pure titanium and those coated with TiN coatings. This work prepared the compound layers and coatings with the same thickness on TA2 pure titanium by plasma nitriding and multi-arc ion plating. The tribological behaviors of sliding against ZrO_2 balls under lubricant conditions were investigated using a UMT-5 tribo-tester. The results reveal that nitrided and coating samples showed the friction coefficients (0.11–0.12) were significantly decreased compared to that (~0.33) of the TA2 pure titanium matrix. It was also found that the wear mechanism is different after nitriding or coating, which is caused by the surface phases, chemical composition, and surface roughness under other processes.

7. Patel Kalpeshkumar et al. Surface irregularities in conjunction with the type of lubricant play an important role to the engine performance and life. Piston skirt contributes to the total friction losses of the piston–cylinder system. This paper presents studies related to piston cylinder surface treatment and related theoretical and experimental works. This paper covering many references, aims to shed new light on the surface modification related to the piston assembly. The work is intended as a reference for surface treatment of piston skirt assembly, with particular emphasis on piston ring. Some studies prove that it is possible to reduce friction and/or reduce wear. It is possible to use special mechanical treatment or chemical coatings and laser structuring treatments to improve the triobological properties of cylinder.

8. H. Zimmerman et al.The concept of incorporating microscopic reservoirs within a hard coating for the purpose of solid lubricant storage and supply during wear of interacting surfaces has been investigated in this study. A novel method was devised using ceramic beads (1.5–10 µmdiameter) as placeholders during the deposition of a TiN coating by reactive sputter deposition. A pin-on-disk wear test was used to test these coatings using graphite and sputter-deposited carbon as the solid lubricant, and an alumina counterface. When tested without any lubricant, the presence of the microreservoirs in the TiN coating appeared to degrade the mechanical integrity of the coating leading to rapid failure. With the graphite lubricant present, the frictional behavior ranged from levels similar to the TiN coating alone, to that of graphite alone. Tests of the TiN coating made using 10 µm beads running against an aluminum counterface showed substantial improvement when the microreservoirs were present. Optical microscopy examination of the wear tracks showed the microreservoirs were generally successful at trapping the graphite lubricant during wear. With a sufficient density and

appropriate distribution of the microreservoirs significant improvements in tribological performance can be realized.

9. PiotrWróblewski et al.Currently, there are many methods of reducing the friction losses of the main components of an internal combustion piston engine. The operating conditions of internal combustion piston engines intended for the propulsion of ultralight aircraft differ significantly from those prevailing in the case of using these engines for the propulsion of vehicles. There are many studies on the influence of selected anti-wear coatings on the friction coefficients when using various lubricants, measured via tribometers. Unfortunately, the conditions obtained in the laboratory significantly differ from those prevailing in an engine operating under external conditions. The study investigated the influence of a change in the tribological parameters of TiN, TiAlN, CrN and DLC1 anti-wear coatings on the moment of resistance to the piston movement of an aircraft engine. The operating parameters of a real engine working in an aircraft were simulated. The main focus was on the coating layers of the sliding surfaces of the piston rings and the cylinder running surface. The properties of the coatings affect the correlation of the scale of the adhesion and cohesion phenomena of the oil to the opposite planes, and this determines the nature of the changes in the moment of resistance to engine motion. As it is commonly known, with an increase in the value of the maximum pressure of the working medium in the combustion chamber, the share of mixed friction in liquid friction increases, similar to the high oil temperatures occurring in aircraft engines. Therefore, there is a justified need to supplement the research in the field of analyzing the characteristics of the torque of resistance to motion for these engines, in particular in the field of the usable rotational speeds of the crankshaft. Applicable anti-wear systems based on selected coatings can significantly improve operational safety and noticeably reduce fuel consumption.

CONCLUSION

piston ring tin coating and laser surface texturing benefits are:

- **Reduced Friction:** Coatings like molybdenum or DLC reduce friction, leading to higher fuel efficiency and better engine performance.
- **Enhanced Durability:** Coatings and texturing can significantly reduce wear and corrosion, increasing the lifespan of piston rings.
- **Improved Heat Management:** Coatings like ceramics or DLC improve heat dissipation, reducing the chances of thermal degradation of piston rings.
- **Lower Emissions:** Reduced friction and improved combustion efficiency contribute to cleaner exhaust gases.

CHALLENGES AND CONSIDERATIONS

- **Cost of Coatings:** Advanced coatings like DLC or ceramic can be expensive to apply, potentially increasing manufacturing costs.
- **Compatibility:** The coatings and texturing methods must be compatible with existing engine materials and designs.

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